ERODIBILITY OF FOREST ANDOSOLS AND SOIL PROPERTIES

C.M. Armas, C.D.Arbelo, J.A. Guerra, J.L. Mora, J.S. Notario and A.R. Rodríguez
Department of Soil Science and Geology, University of La Laguna, Canary Islands, Spain.

Abstract
The sensitivity of Andosols to water erosion in a forest environment (Garajonay National Park, Gomera, Canary Islands) has been studied by evaluating USLE's erodibility factor (K), the actual susceptibility of soil to separation by means of two tests for measuring the stability of aggregates, and its relationship with relevant physicochemical properties. The results show the limited validity of the conventional estimation of erodibility in andic soils, where the sensitivity towards erosion is mostly related to their content in organometallic compounds.

Additional Keywords: Canary Islands, aggregate stability, disaggregation, organometallic compounds

Introduction
In general, according to the classical evaluation of erodibility (Wischmeier *et al*., 1971) andic soils are attributed little vulnerability to water erosion. In spite of this, it is demonstrated that andic soils can be affected by important erosive processes, especially resulting from changes in land use or management. In this context, evaluation of the aggregation and structural stability of the soils gives an indirect measure of the erodibility (Imeson and Vis, 1984; Lal, 1988) and can give an accurate description of the mechanisms of particle separation in andic soils (Rodríguez Rodríguez *et al*., 2002).

The present study aims to evaluate the theoretical erodibility (K factor) and the sensitivity to erosion via the structural stability in relation to the two mechanisms most directly involved in the first stages of water erosion: water drop impact and disaggregation by humectation, in andic soils under forest vegetation and to identify the physicochemical properties of the soils more directly involved in their erodibility.

Material and Methods
Field Site
The study area was situated in the Garajonay National Park (La Gomera, Canary Islands) at altitudes of between 650 and 1435 m.a.s.l. The typical vegetation corresponds to laurel forests although heathland, leguminous shrubs and conifer plantations are also frequent. Soil temperature/moisture regimes are thermic/Udic-Ustic, respectively. The soils in the Park are mainly Andosols and Leptosols, with nuclei of Cambisols, Umbrisols and Luvisols.

Sampling was made taking areas of 1000x500m as a reference all over the Garajonay national Park, increasing the sampling density to areas of 250x250m in those sectors most degraded and most affected by erosion. In total, 163 sites were studied, a soil sample was collected and the morphology of the soil and terrain was described in each one.

Analysis
In the soil samples, aggregate stability was studied using two different tests:

(a) Wet sieving test (Bartoli *et al*., 1991) to measure dispersion of the structure due to humectation of the aggregates: samples of the aggregates are placed in sieves partially submerged in distilled water and submitted to oscillations with a 2 cm amplitude at a frequency of 98 oscillations per minute. Previous works indicate a period of 6 hours as appropriate for disaggregation of these soils in water (Rodríguez Rodríguez *et al*., 2002).
(b) Water-drop impact test (Imeson and Vis, 1984), as a measure of the disaggregation due to the direct impact of rain drops. The equipment used produces water-drops weighing 0.1g that fall at a rate of 1 drop per second from a height of 1 m before landing on the aggregates. The parameter evaluated was the exact number of droplets required to cause dispersion of the aggregates so that these can pass through a sieve with a 0.2 mm mesh (CND, "Counting the Number of Drops"), up to a maximum of 60 drops.

Different physicochemical properties were studied, especially those related to short-range ordered minerals and organic components, the association of which is responsible for the structural stability of the Andosols (Warkentin and Maeda, 1980):

- Contents of iron and aluminium extractable with sodium pyrophosphate and with ammonium oxalate/oxalic acid.
- Total carbon and nitrogen contents.
- Fractionation of organic matter into humic and fulvic acids (Duchafour and Jacquin, 1966).
- Speciation of organic carbon by sequential extraction with sodium pyrophosphate and potassium sulphate (Calvo and Macías, 2001). Fractions of labile organ carbon (LOC), complexed organic carbon (COC) and oxidizable carbon not extractable by the cited methods (OOC) were also studied.
- Granulometric composition

USLE K factor was calculated using the equation of Wischmeier *et al*. (1971), on the basis of analytical parameters and the field description.

Results and Discussion

The samples studied mainly belong to andic soils (53%) according to FAO criteria (WRB, 1998), with a predominance of non-allophanic Andosols (40%) compared to allophanic Andosols (13%). The structural stability to humectation and water-drop impact of the soils studied is, in general, very high (Table 1). The non-allophanic Andosols generally have higher CND values but relevant differences are not found between the three soil groups. This behavior is not reflected in USLE's K factor that is significantly lower in andic soils than in non-andic soils. Table 2 shows the correlation between the structural stability, the theoretical erodibility (K factor) and some soil properties. USLE's K factor only showed some relation with susceptibility to separation in the tests used in non-andic soils.

Table 1. Erodibility measurements in the soils studied

	Comparative statistical test *	Non-andic soils	Non-allophanic Andosols	Allophanic Andosols
Water-stable aggregates (%)	ANOVA	78.3 ± 11.7a	79.9 ± 10.7 a	76.8 ± 7.4 a
CND**	Kruskal-Wallis, U Mann-Whitney	38 ± 23 a	47 ± 20 b	34 ± 27 a
K-USLE (tyearMJ^{-1}mm^{-1})	ANOVA	0.26 ± 0.36 a	0.04 ± 0.03 b	0.10 ± 0.11 b
*Groups with the same letter are not significantly different according to the statistical test used (p≤0,05).				

**CND = Nº of drops required to completely break up the aggregate

In non-andic soils, disaggregation in humectation is highly correlated with the particle size distribution and the degree of humectation and complexation of organic carbon, and seems to be related with a structure stabilized by the formation of clay-humic complexes. In the allophonic Andosols, disaggregation by humectation is correlated with fractions of organic carbon while in the non-allophanic Andosols there are no significant correlations with the soil properties studied (Figure 1).

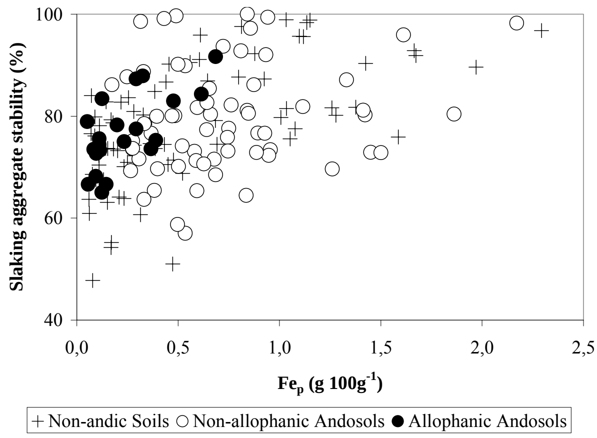

Figure 1. Relationship between stability to disaggregation and the formation of organomineral complexes (Fe$_p$)

Table 2. Correlation between structural stability and physicochemical properties in the soil groups studied

	Non-andic soils		Non-allophanic Andosols		Allophanic Andosols	
	Slaking	CND**	Slaking	CND**	Slaking	CND**
Stability to slaking	-	0.346*	-	0.506*	-	0.497*
Stability in drop impact (CND**)	0.346*	-	0.506*	-	0.497*	-
K-USLE	-0.203	-0.420*	-0.205	0.203	-0.026	-0.192
Fine fraction (clay + lime)	0.257*	0.077	0.224	-0.004	0.084	0.315
Al_o***	-0.041	0.128	-0.084	0.074	0.246	0.310
Fe_o***	0.360*	-0.017	0.155	0.229	0.086	0.385
$Al_o + ½Fe_o$***	0.134	0.101	-0.025	0.164	0.243	0.327
Fe_p***	0.598*	0.387*	0.185	0.371*	0.672*	0.602*
Al_p***	0.510*	0.343*	-0.179	0.214	0.622*	0.432
$Al_p + ½Fe_p$***	0.553*	0.367*	-0.117	0.270*	0.642*	0.469*
$C_p/(Al_p+Fe_p)$***	-0.267*	0.022	0.024	-0.057	-0.426	-0.245
OOC ****	0.157	0.309*	-0.174	0.126	0.438*	0.381
COC ****	0.492*	0.429*	-0.032	0.318*	0.553*	0.446*
LOC ****	0.195	0.208	-0.120	0.218	0.293	0.480*
Humified organic matter	0.430*	0.363*	-0.039	0.256*	0.548*	0.420
Fulvic acids	0.470*	0.473*	0.062	0.355*	0.553*	0.411
Humic acids	0.356*	0.246*	-0.121	0.115	0.376	0.298
C/N ratio	-0.183	-0.014	-0.116	0.145	0.208	0.476
*Significant correlation at a significance level of $p \leq 0.05$						

**CND = Nº of water-drops required for complete rupture of the aggregate
***Al_o,Fe_o = Al, Fe extractable with oxalic acid, Al_p,Fe_p,C_p = Al, Fe, C extractable with sodium pyrophosphate.
***OOC = Oxidizable organic carbon, COC = Complexed organic carbon, LOC = Labile organic carbon

The stability to water-drop impact is correlated in all the groups with the contents of complexed/humified organic carbon and iron and aluminium bound to organic compounds. In the non-allophanic Andosols, disaggregation by water-drop impact is the main separation mechanism determined by the physicochemical properties studied (Figure 2).

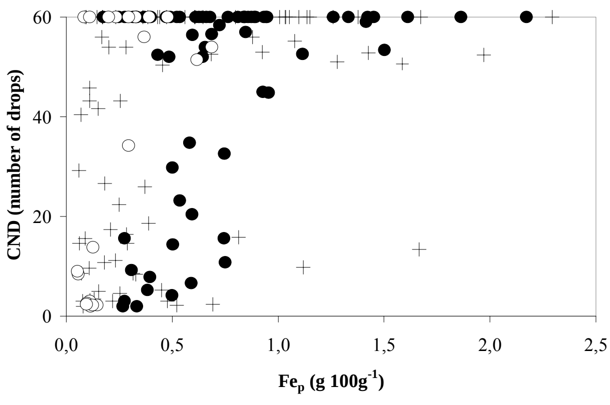

Figure 2. Relationship between stability to water-drop impact and formation of organomineral complexes (Fe_p)

Soil properties are closely correlated and this is reflected by their high colinearity and a high redundancy in the explanatory power of the variation observed in aggregate stability. Hence, four variables (Fe_p, $C_p/(Al_p+Fe_p)$, C in the form of fulvic acids and fine granulometric fraction) explain 29% of the variance observed in the stability of the aggregates in humectation, compared to 35% variance explained by all the properties studied taken together.

Similarly, only two variables (organic carbon in the form of fulvic acids and the fine granulometric fraction) explain 26% of the variance observed in the stability of aggregates to water-drop impact compared to 45% explained by all the properties considered together.

According to Rodríguez Rodríguez *et al*. (2002), erosion in andic soils is mainly caused by the impact of raindrops on soil aggregates. The results of this study also suggest that mechanisms of stabilization and separation of the structure exist, characteristic of the soil groups considered. The impact of raindrops seems to be the most important disaggregation mechanism in organomineral andosols (non-allophanic ones) although this is common in all soil groups and is related with the organic carbon content in complexed or humic forms. Disaggregation in humectation does not occur in non-allophanic Andosols and is typical of soils stabilized by clay-humic complexes.

Conclusions

USLE erodibility K factor does not suitably characterize susceptibility of Andosols to erosion whereas it adequately reflects susceptibility to separation in non-andic soils of the zone studied. The results emphasize the importance of water-drop impact mechanisms breakdown of Andosol aggregates, especially those with larger contents of organo-mineral complexes where these are the main destabilization mechanisms. In andic soils, aggregate stability tests give a more accurate measure of the erodobility of these soils than calculation of USLE K factor. Evaluation of the erodibility of these soils based on a parametric model should give importance to the degree of humification or complexation of the organic matter, as compared to other parameters such as granulometric composition.

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